Dynamic dispatch of cascaded hydro systems

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Transmission planning in thermal systems

1. Select "snapshots" of dispatch scenarios
   - usually peak load condition
2. Design network reinforcements "around" those dispatch points
   - eliminate overloads and bus voltage violations
   - no tradeoff between transmission costs and generation redispatch costs; no representation of dynamic evolution

Dynamic simulation may not be necessary

- Transmission investments costs are relatively smaller than generation costs $\Rightarrow$ no congestions in the "optimal" network
- Economic dispatch is decoupled in time

What about hydro systems?

- transmission investments are higher
  - Hydro plants are more distant
  - Transfer of energy blocks in different directions, depending on hydrology

    $\Rightarrow$The "optimal" network may have some congestions
  - Stronger coupling between G&T investment decisions
- economic hydro dispatch has more "degrees of freedom"

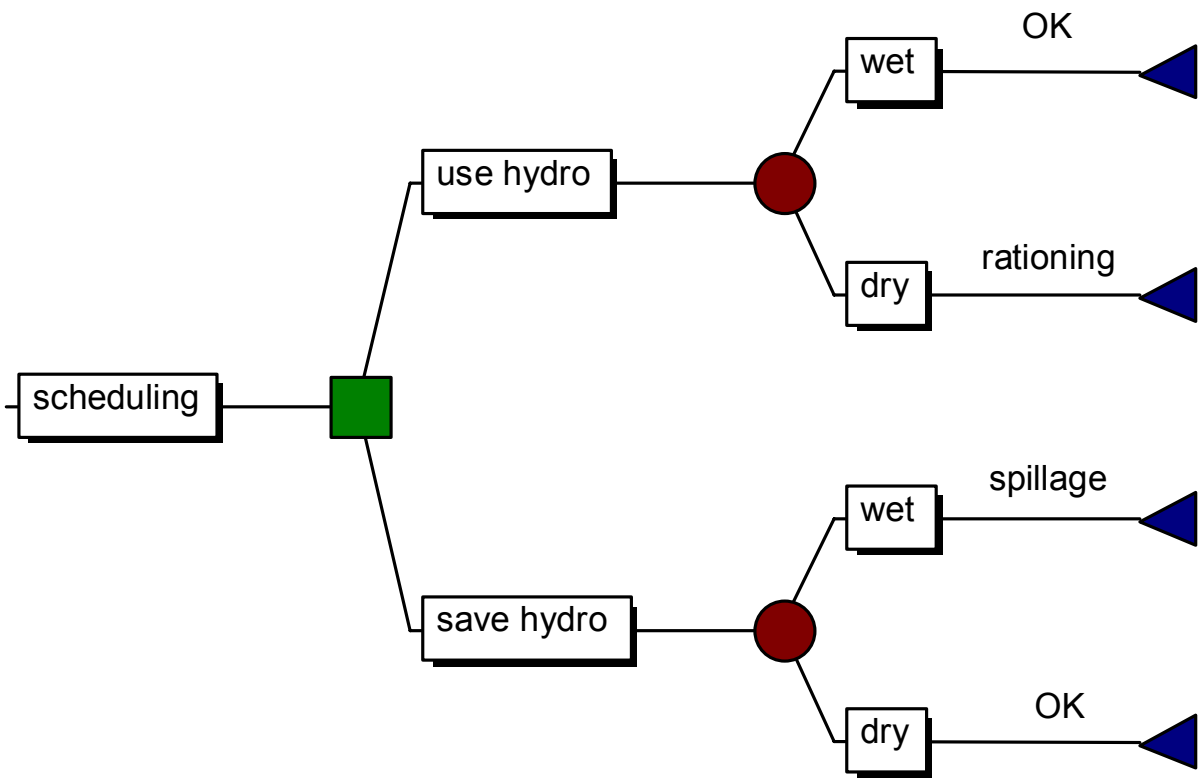
  $\Rightarrow$ tradeoff between redispatching hydro and postponing transmission investments

Transmission planning in hydro systems may require dynamic dispatch simulation

Hydrothermal scheduling model

- cascaded hydro
  - water balance, spillage, filtration, evaporation, irrigation, "salmon" constraints etc.
- inflow uncertainty
  - multivariate stochastic inflow models which represent both spatial and time dependence.
- thermal plants
  - efficiency curves, fuel limits, startup costs, multiple fuels etc
- transmission network
  - "loop flows", quadratic losses, power flow limits, area exports, security constraints etc.

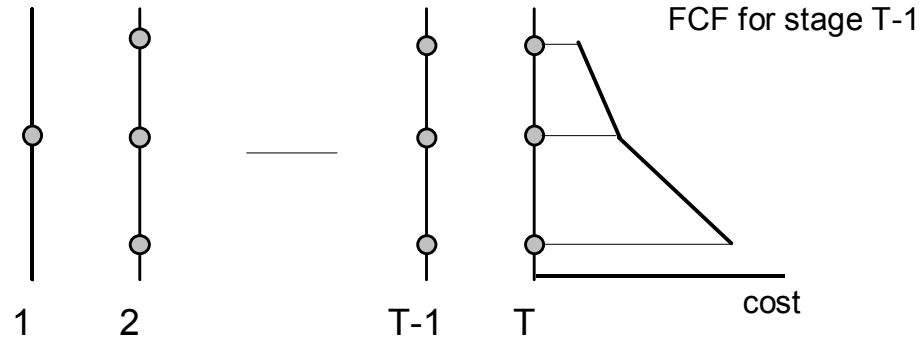
Time dependence + inflow uncertainty



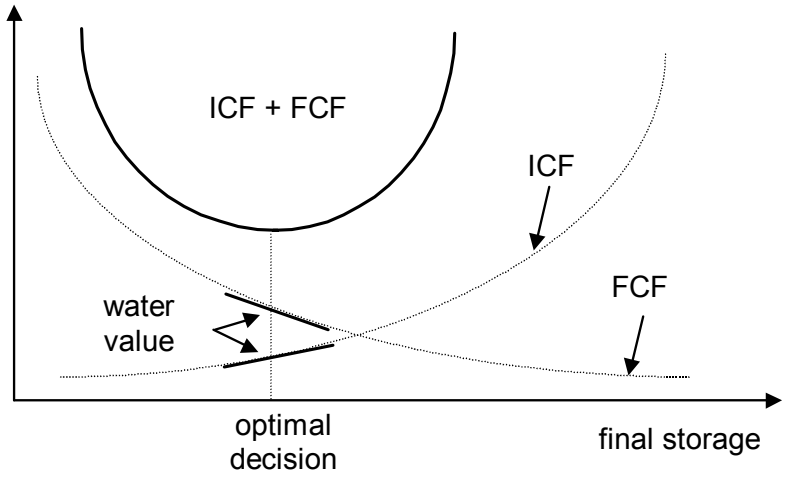
- **The number of branches in the decision tree increases exponentially**

Traditional approach: stochastic DP

- Backward recursion that minimizes sum of immediate and future costs



- derivatives of ICF and FCF with respect to storage are equal and opposite: water values

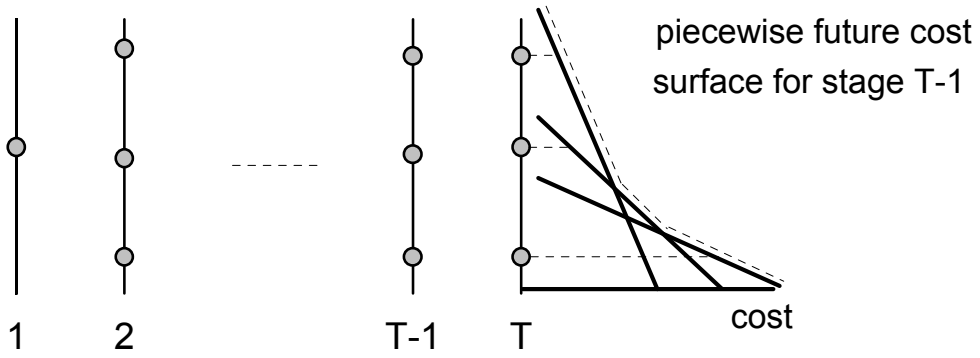


Limitation of Traditional SDP

- computational effort increases exponentially with number of reservoirs ("curse of dimensionality")
  - Applications limited to three or four hydro plants

Stochastic Dual DP

- SDDP avoids the curse of dimensionality by creating a piecewise linear FCF



- It becomes possible to simulate systems with hundreds of hydro plants

Example: Brazil

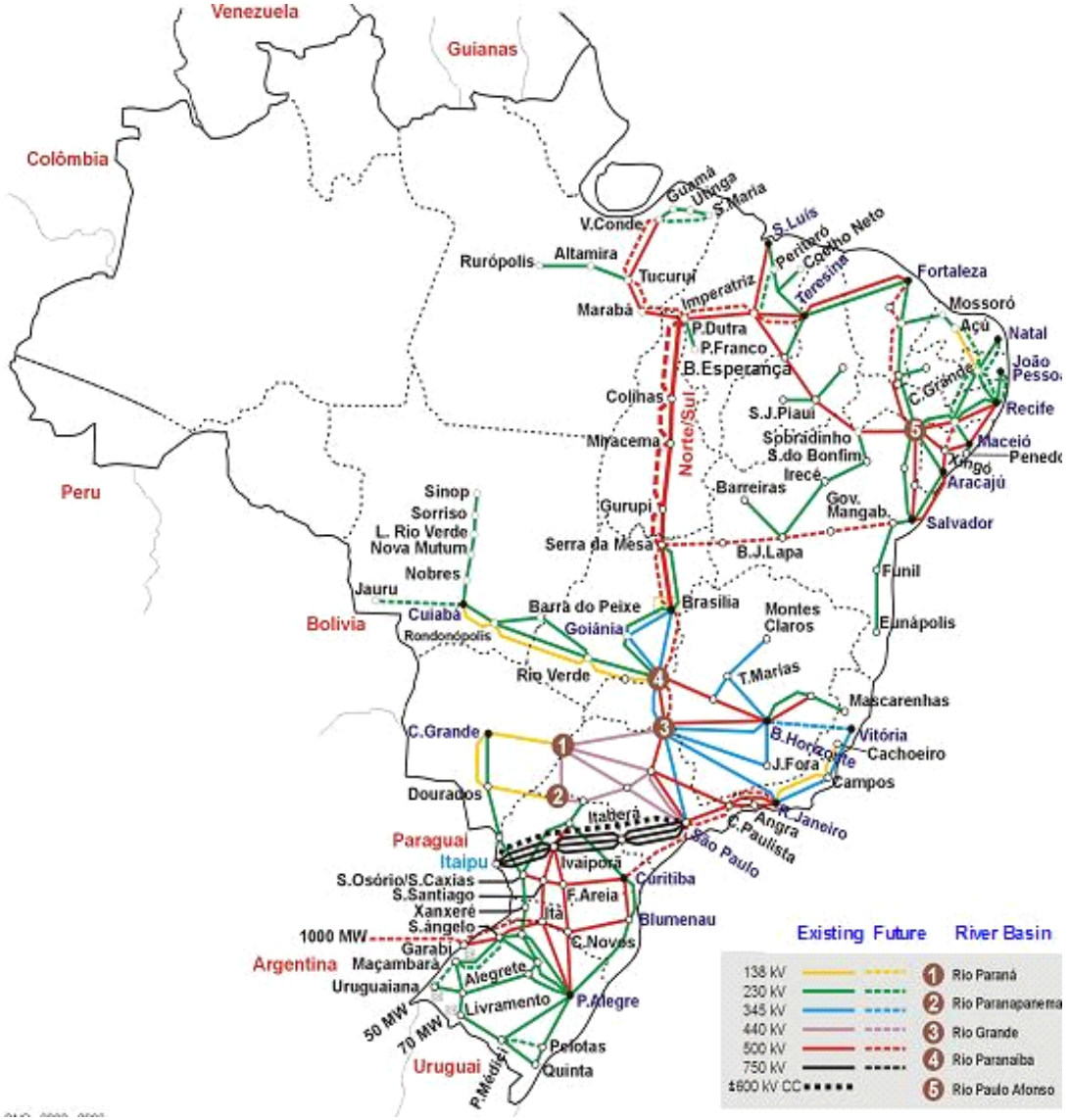
Surface area: 8.5 million sq km

(= continental USA + 1/2 Alaska)

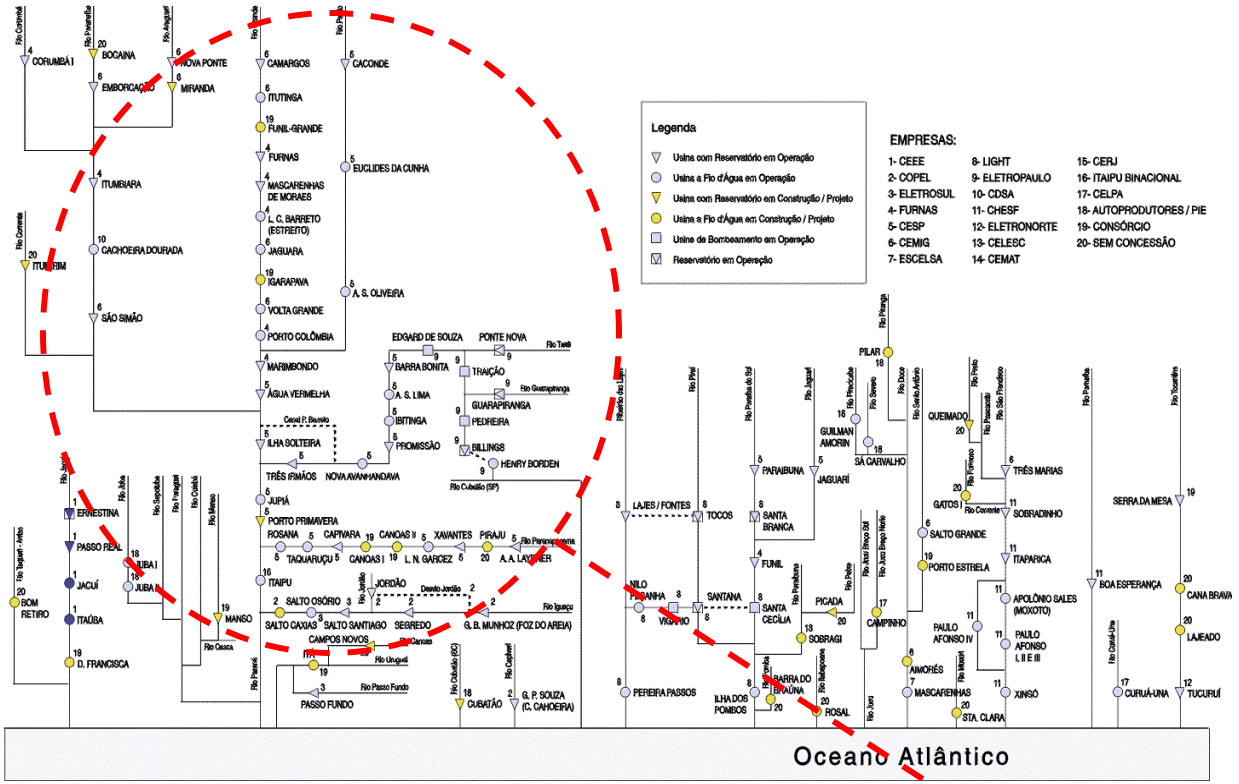
Inst.capacity: 85,000 MW (85% hydro)

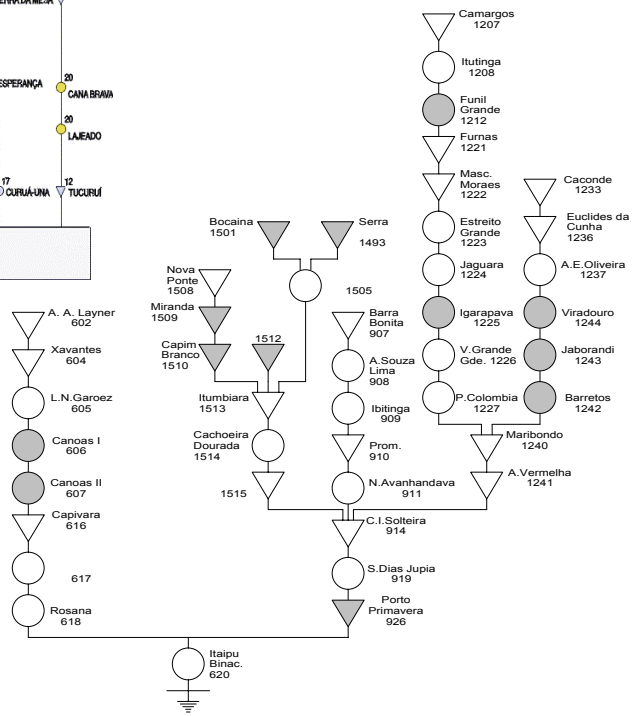
The whole country is interconnected by 80,000 km of HV lines

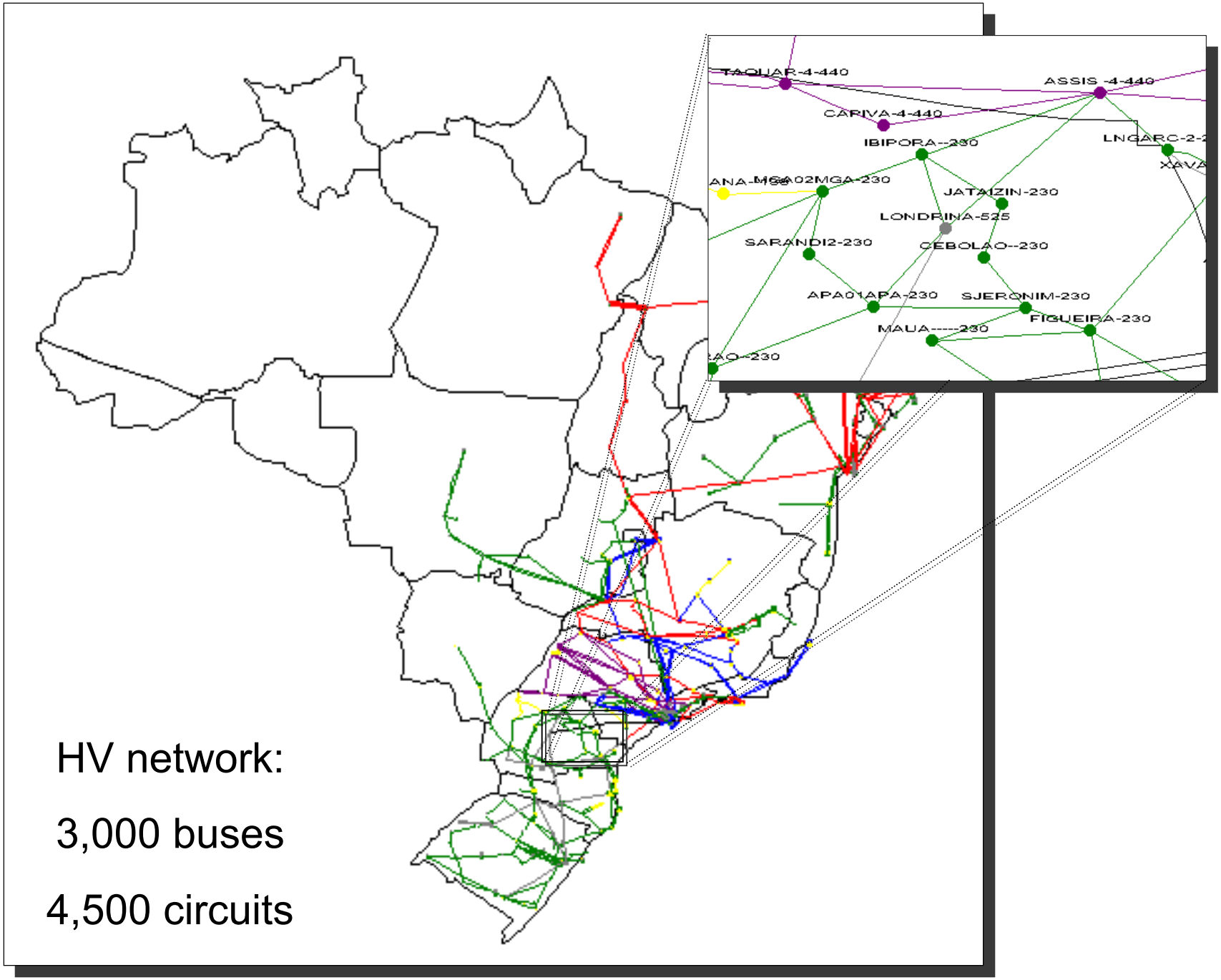
Additional 40,000 km of HV circuits will be added in the next 8 years



Hydro Chains



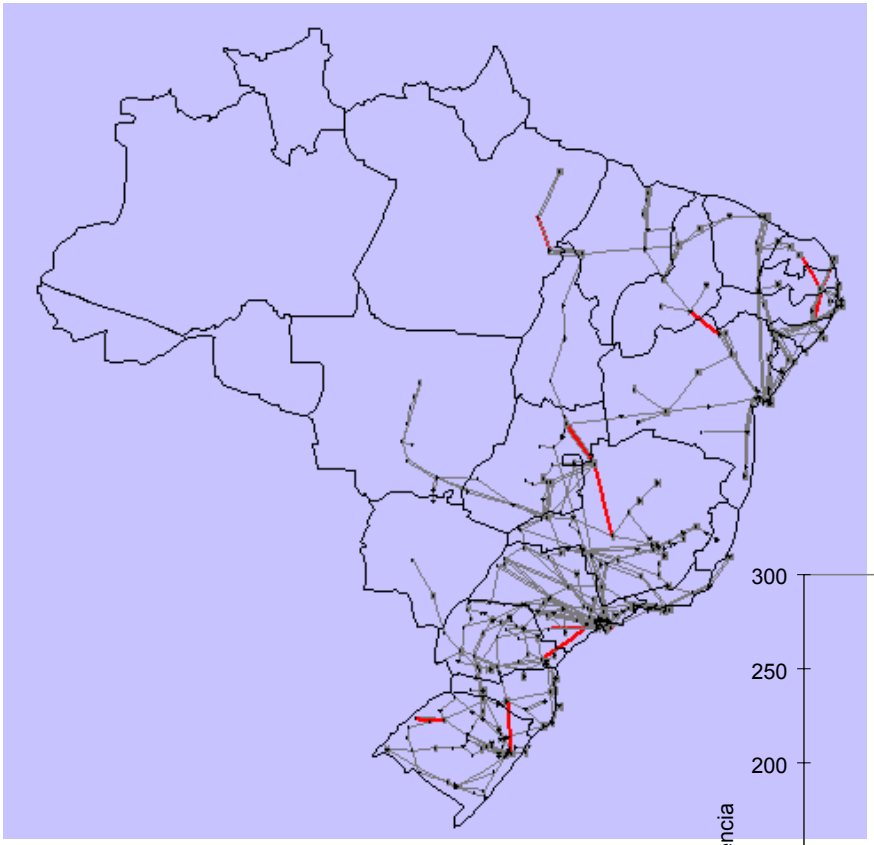


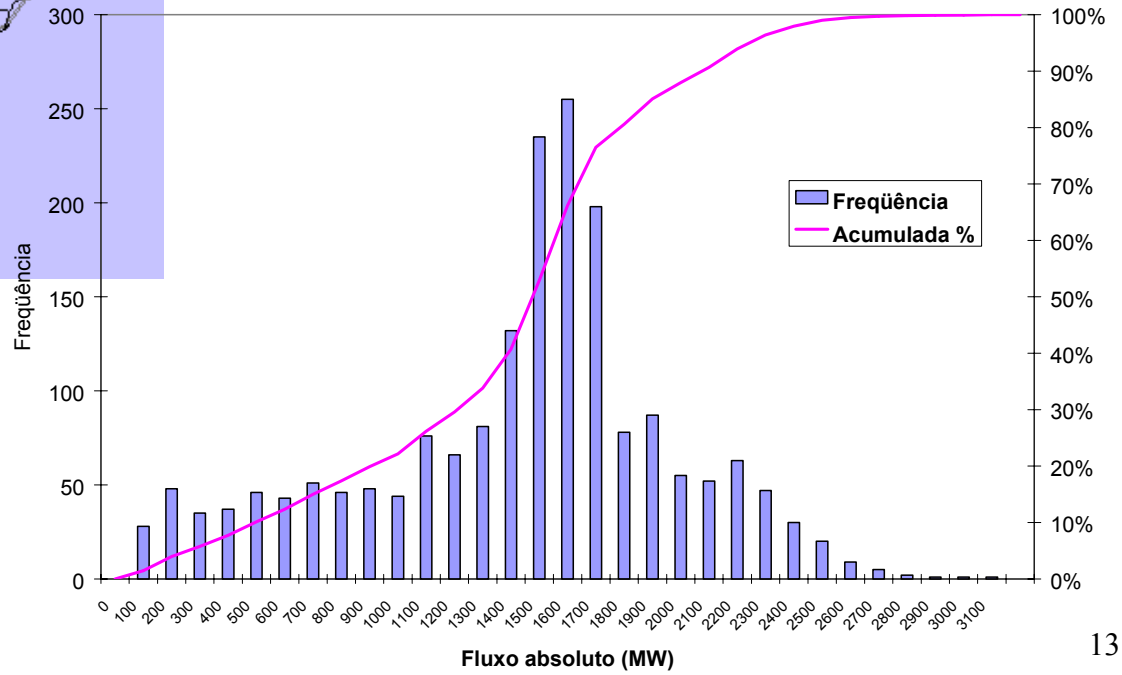

TAQUAR-4-440
ASSIS -4-440
CARIVA-4-440
IBIPORA--230
LNGARC-2-2
XAVA
ANA-MGA
02MGA-230
JATAIZIN-230
LONDRINA-525
SARANDI2-230
CEBOLAO--230
APA01APA-230
SJERONIM-230
FIGUEIRA-230
MAUA-----230
AO-230
HV network:
3,000 buses
4,500 circuits

Typical study

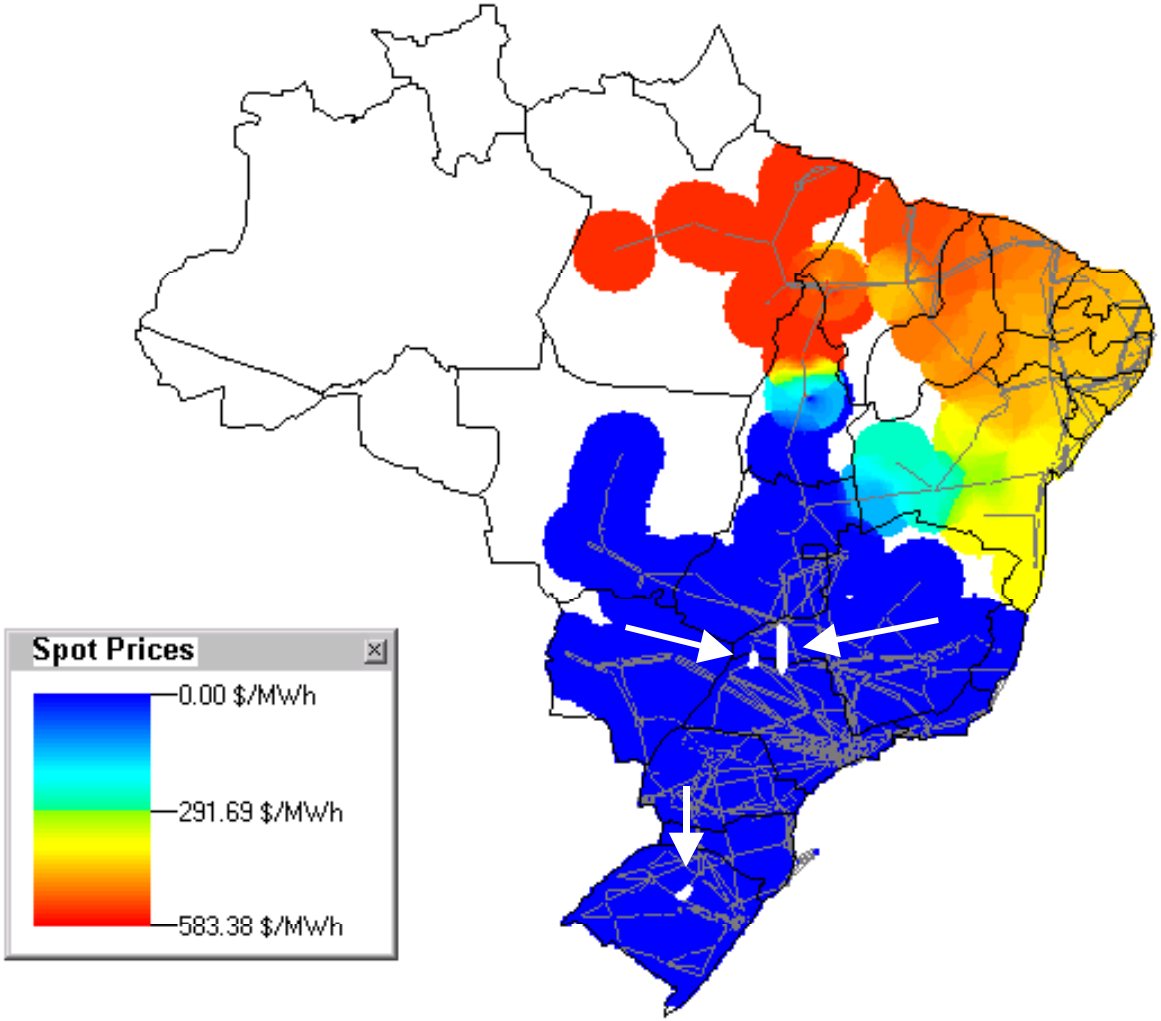
- Generation & Transmission
  - 120 hydro power plants
  - 80 thermal power plants (gas, nuclear, coal, diesel)
  - 2,900 buses
  - 4,500 circuits
- Planning horizon
  - 120 months (60 months + 5 “buffer” years)
  - 3 load blocks
- Inflow model
  - Multivariate ARP
  - Simulation for 200 inflow scenarios

Results: overloaded circuits





Results: LMPs



Conclusions

- Stochastic Dual DP is an effective technique for the integrated simulation of cascaded hydro systems and transmission networks
  - Tool for transmission planning studies
- Allows analysis of topics of interest to the West Coast:
  - Coordination of "across the border" cascades with different operators
  - Impact of LMPs and congestion payments on hydro revenues